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Marked Up Version of Amendments

Submitted with Second Preliminary Amendment

In the Specification:

On page 31, the two paragraphs beginning on line 22:

FIGS. 51-57-56 depict several embodiments of heat sources in a relatively low permeability formation;

FIGS. 58-57-70 depict several embodiments of a heat source and production well pattern;

On page 34, the paragraph beginning on line 29:

FIG. 133 depicts cumulative condensable hydrocarbons ~~and water~~ as a function of temperature produced by heating a coal cube;

On page 35, the three paragraphs beginning on line 15 (as amended in the Preliminary Amendment):

FIG. 144 depicts percentage ethene to ethane produced from a coal formation as a function of heating rate in ~~an experimental field~~ ~~a laboratory~~ test;

FIG. 145 depicts product quality of fluids produced from a coal formation as a function of heating rate in ~~an experimental field~~ ~~a laboratory~~ test;

FIG. 146 depicts weight percentages of various fluids produced from a coal formation for various heating rates in ~~an experimental field~~ ~~a laboratory~~ test;

On page 71, the paragraph beginning on line 26:

FIG. 9 illustrates an embodiment of unit cell 404. Unit cell 404 includes heat

sources 400 and production wells 402. Unit cell 404 may have six full heat sources 400a and six partial heat sources 400b. Full heat sources 400a may be closer to production well 402 than partial heat sources 400b. In addition, an entirety of each of the full heat sources 400a may be located within unit cell 404. Partial heat sources 400b may be partially disposed within unit cell 404. Only a portion of heat source 400b disposed within unit cell 404 may be configured to provide heat to a portion of a hydrocarbon containing formation disposed within unit cell 404. A remaining portion of heat source 400b disposed outside of unit cell 404 may be configured to provide heat to a remaining portion of the hydrocarbon containing formation outside of unit cell 404. Therefore, to determine a number of heat sources within unit cell 404 partial heat source 400b may be counted as one-half of full heat sources 400a. In other unit cell embodiments, fractions other than 1/2 (e.g., 1/3) may more accurately describe the amount of heat applied to a portion from a partial heat source.

On page 107, the paragraph beginning on line 11:

FIG. 23a illustrates a cross-sectional view of an embodiment of a centralizer 581e 581 disposed on conductor 580. FIG. 23b illustrates a perspective view of the embodiment shown in FIG. 23a. Centralizer 581e 581 may be made of any suitable electrically insulating material that may substantially withstand high voltage at high temperatures. Examples of such materials may be aluminum oxide and/or Macor. Discs 581d may maintain positions of centralizer 581e 581 relative to conductor 580. Discs 581d may be metal discs welded to conductor 580. Discs 581d may be tack-welded to conductor 580. Centralizer 581e 581 may substantially electrically insulate conductor 580 from conduit 582.

On page 119, the paragraph beginning on line 26:

Oxidizing fluid 624-623 may mix with fuel fluid 621 in the oxidation region of inner conduit 638. Either oxidizing fluid 623 or fuel fluid 621, or a combination of both,

may be preheated external to the combustor to a temperature sufficient to support oxidation of fuel fluid 621. Oxidation of fuel fluid 621 may provide heat generation within outer conduit 636. The generated heat may provide heat to at least a portion of a hydrocarbon containing formation proximate to the oxidation region of inner conduit 638. Products 625 from oxidation of fuel fluid 621 may be removed through outer conduit 636 outside inner conduit 638. Heat exchange between the downgoing oxidizing fluid and the upgoing combustion products in the overburden results in enhanced thermal efficiency. A flow of removed combustion products 625 may be balanced with a flow of fuel fluid 621 and oxidizing fluid 623 to maintain a temperature above autoignition temperature but below a temperature sufficient to produce substantial oxides of nitrogen. Also, a constant flow of fluids may provide a substantially uniform temperature distribution within the oxidation region of inner conduit 638. Outer conduit 636 may be, for example, a stainless steel tube. In this manner, heating of at least the portion of the hydrocarbon containing formation may be substantially uniform. As described above, the lower operating temperature may also provide a less expensive metallurgical cost associated with the heating system.

On pages 135-137, Tables 2a-2g:

TABLE 2a

| API Gravity | <u>A</u> | <u>B</u> |
|-------------|----------|----------|
| 20 degrees | -59906.9 | 83.46594 |
| 25 degrees | -43778.5 | 66.85148 |
| 30 degrees | -30864.5 | 50.67593 |
| 35 degrees | -21718.5 | 37.82131 |
| 40 degrees | -16894.7 | 31.16965 |
| 45 degrees | -16946.8 | 33.60297 |

TABLE 2b

| Ethene/Ethane Ratio | <u>A</u> | <u>B</u> |
|------------------------|----------|----------|
| 0.20 | -57379 | 83.145 |
| 0.10 | -16056 | 27.652 |
| 0.05 | -11736 | 21.986 |
| 0.01 | -5492.8 | 14.234 |

TABLE 2c

| Weight Percent of Hydrocarbons Having a Carbon Number Greater Than 25 | <u>A</u> | <u>B</u> |
|---|----------|----------|
| 25 % | -14206 | 25.123 |
| 20 % | -15972 | 28.442 |
| 15 % | -17912 | 31.804 |
| 10 % | -19929 | 35.349 |
| 5 % | -21956 | 38.849 |
| 1 % | -24146 | 43.394 |

TABLE 2d

| Atomic H/C Ratio | <u>A</u> | <u>B</u> |
|------------------|----------|----------|
| 1.7 | -38360 | 60.531 |
| 1.8 | -12635 | 23.989 |
| 1.9 | -7953.1 | 17.889 |
| 2.0 | -6613.1 | 16.364 |

TABLE 2e

| Liquid Production (gal/ton) | <u>A</u> | <u>B</u> |
|--------------------------------|----------|----------|
| 14 gal/ton | -10179 | 21.780 |
| 16 gal/ton | -13285 | 25.866 |
| 18 gal/ton | -18364 | 32.882 |
| 20 gal/ton | -19689 | 34.282 |

TABLE 2f

| Equivalent Liquid Production (gal/ton) | <u>A</u> | <u>B</u> |
|---|----------|----------|
| 20 gal/ton | -19721 | 38.338 |
| 25 gal/ton | -23350 | 42.052 |
| 30 gal/ton | -39768.9 | 57.68 |

TABLE 2g

| % Fischer Assay | <u>A</u> | <u>B</u> |
|-----------------|----------|----------|
| 60 % | -11118 | 23.156 |
| 70 % | -13726 | 26.635 |
| 80 % | -20543 | 36.191 |
| 90 % | -28554 | 47.084 |

On page 172, the paragraph beginning on line 25:

FIG. 40 depicts an embodiment of in situ synthesis gas production integrated with a catalytic methanation process. For example, synthesis gas 1140 exiting production well 1142 may be supplied to catalytic methanation plant 1144. In some embodiments, it may be desirable for the composition of produced synthesis gas, which may be used as a feed gas for a catalytic methanation process, to have a H₂ to carbon monoxide ratio of about

On page 206, the paragraph beginning on line 12:

Power generation unit 2822 may be configured for extracting useable energy from the first portion of stream 2818. For example, stream 2818 may be produced under pressure. In this manner, power generation unit 2822 may include a turbine configured to generate electricity from the first portion of stream 2818. The power generation unit may also include, for example, a molten carbonate fuel cell, a solid oxide fuel cell, or other type of fuel cell. The facilities may be further configured such that the extracted useable energy may be provided to user 2824. User 2824 may include, for example, surface facilities 2800, a heat source disposed within a formation, and/or a consumer of useable energy.

On page 212, the paragraph beginning on line 10:

FIG. 75 illustrates an example of another pattern of heat sources 3000 and production wells 3002. Midlines 3006 are formed equidistant from the two production wells 3002, and perpendicular to a line connecting such production wells. Unit cell 3014 is determined by intersection of midlines 3006 at vertices 3008. Twelve heat sources 3000 are counted in unit cell 3014 by a method as described in the above embodiments, of which ~~are~~ six are whole sources of heat, and six are one third sources of heat (with the other two thirds of heat from such six wells going to other patterns). Thus, a ratio of heat sources 3000 to production wells 3002 is determined as 8:1 for the pattern illustrated in FIG. 75. An example of a pattern of heat sources is illustrated in U.S. Patent No. 2,923,535 issued to Ljungstrom, which is incorporated by reference as if fully set forth herein.

On page 216, the paragraph beginning on line 4:

FIG. 81b illustrates a comparison plot between the average pattern temperature and temperatures at the coldest spots for each pattern, as a function of time when heaters are turned off after the average temperature reaches a target value. As shown in FIG. 81b, an average temperature 3120 of the formation reaches a target temperature (about 340 °C) in approximately 3 years (about 340 °C). As shown in FIG. 81b, a temperature at the coldest point within the triangular pattern 3118 reaches the target temperature (about 340 °C) about 0.8 years later. In this manner, a total process time for such a triangular pattern is about 3.8 years when the heat input is discontinued when the target average temperature is reached. As shown in FIG. 81b, a temperature at the coldest point within the triangular pattern reaches the target temperature (about 340 °C) before a temperature at the coldest point within the square pattern 3117 or a temperature at the coldest point within the hexagonal pattern 3114 reaches the target temperature. A temperature at the coldest point within the hexagonal pattern, however, reaches the target temperature after an additional time of about 2 years when the heaters are turned off upon reaching the target average temperature. Therefore, a total process time for a hexagonal pattern is about 5.0 years. In this manner, a total process time for heating a portion of a formation with a triangular pattern is 1.2 years less (approximately 25 %) than a total process time for heating a portion of a formation with a hexagonal pattern. In a preferred mode, the power to the heaters may be reduced or turned off when the average temperature of the pattern reaches a target level. This prevents overheating the resource, which wastes energy and produces lower product quality. The triangular pattern has the most uniform temperatures and the least overheating. Although a capital cost of such a triangular pattern may be approximately the same as a capital cost of the hexagonal pattern, the triangular pattern may accelerate oil production and requires a shorter total process time. In this manner, such a triangular pattern may be more economical than a hexagonal pattern.

On page 225, the paragraph beginning on line 14:

In FIG. 90, a plot of gauge pressure versus temperature is depicted (in FIGS. 90-

96 the pressure is indicated in bars). Lines representing the fraction of products with carbon numbers greater than about 25 were plotted. For example, when operating at a temperature of 375 °C and a pressure of 2.74.5 bars absolute, 15 % of the produced fluid hydrocarbons had a carbon number equal to or greater than 25. At low pyrolysis temperatures and high pressures, the fraction of produced fluids with carbon numbers greater than about 25 decreases. Therefore, operating at a high pressure and a pyrolysis temperature at the lower end of the pyrolysis temperature zone tends to decrease the fraction of fluids with carbon numbers greater than 25 produced from oil shale.

On page 225, the paragraph beginning on line 24 (as amended in the Preliminary Amendment):

FIG. 91 illustrates oil quality produced from an oil shale formation as a function of pressure and temperature. Lines indicating different oil qualities, as defined by API gravity, are plotted. For example, the quality of the produced oil was 4540° API when pressure was maintained at about 6-11.1 bars absolute and a temperature was about 375 °C. As described in above embodiments, low pyrolysis temperatures and relatively high pressures may produce a high API gravity oil.

On page 226, the two paragraphs beginning on line 1 (as amended in the Preliminary Amendment):

FIG. 92 illustrates an ethene to ethane ratio produced from an oil shale formation as a function of pressure and temperature. For example, at a pressure of 11.221.7 bars absolute and a temperature of 375 °C, the ratio of ethene to ethane is approximately 0.01. The volume ratio of ethene to ethane may predict an olefin to alkane ratio of hydrocarbons produced during pyrolysis. To control olefin content, operating at lower pyrolysis temperatures and a higher pressure may be beneficial. Olefin content in above described embodiments may be reduced by operating at low pyrolysis temperature and a high pressure.

On page 228, the paragraph beginning on line 6:

FIG. 97 is an example of such a plot for olefin to paraffin ratio. Data from the above experiments were compared to data from other sources. Isobars were plotted on a temperature versus olefin to paraffin ratio graph using data from a variety of sources. Data from the above described experiments included an isobar at 1 bar absolute 3360, 2.5 bars absolute 3362, 4.5 bars absolute 3364, 7.9 bars absolute 3366, and 14.8 bars absolute 3368. Additional data plotted included data from a surface retort, data from Ljungstrom 3361, and data from ex situ oil shale studies conducted by Lawrence Livermore Laboratories 3363. As illustrated in FIG. 97, the olefin to paraffin ratio appears to increase as the pyrolysis temperature increases. However, for a fixed temperature, the ratio decreases rapidly with an increase in pressure. Higher pressures and lower temperatures appear to favor the lowest olefin to paraffin ratios. At a temperature of about 325-350 °C and a pressure of about 4.5 7.9 bars absolute 3366, a ratio of olefins to paraffins was approximately 0.01. Pyrolyzing at reduced temperature and increased pressure may decrease an olefin to paraffin ratio. Pyrolyzing hydrocarbons for a longer period of time, which may be accomplished by increasing pressure within the system, tends to result in a lower average molecular weight oil. In addition, production of gas may increase and a non-volatile coke may be formed.

On page 238, the paragraph beginning on line 9:

As shown in Table 4, gas produced according to an embodiment described herein may be treated and sold through existing natural gas systems. In contrast, gas produced by typical in situ gasification processes may not be treated and sold through existing natural gas systems. For example, a heating value of the gas produced by gasification with air was 6000 KJ/m³, and a heating value of gas produced by gasification with oxygen was 11,439 KJ/m³. In contrast, a heating value of the gas produced by thermal conductive heating was 39,159 KJ/m³.

On page 244, the paragraph beginning on line 10 (as amended in the Preliminary Amendment):

Hydrocarbon fluids were produced from a portion of a coal formation by an in situ experiment conducted in a portion of a coal formation. The coal was high volatile bituminous C coal. It was heated with electrical heaters. FIG. 136 illustrates a cross-sectional view of the in situ experimental field test system. As shown in FIG. 136, the experimental field test system included at least coal formation 3802 within the ground and grout wall 3800. Coal formation 3802 dipped at an angle of approximately 36° with a thickness of approximately 4.9 meters. FIG. 137 illustrates a location of heat sources 3804a, 3804b, 3804c, production wells 3806a, 3806b, and temperature observation wells 3808a, 3808b, 3808c, 3808d used for the experimental field test system. The three heat sources were disposed in a triangular configuration. Production well 3806a was located proximate a center of the heat source pattern and equidistant from each of the heat sources. A second production well 3806b was located outside the heat source pattern and spaced equidistant from the two closest heat sources. Grout wall 3800 was formed around the heat source pattern and the production wells. The grout wall ~~may include pillars~~ was formed of 24 pillars. Grout wall 3800 was configured to inhibit an influx of water into the portion during the in situ experiment. In addition, grout wall 3800 was configured to substantially inhibit loss of generated hydrocarbon fluids to an unheated portion of the formation.

On page 250, the paragraph beginning on line 2 (as amended in the Preliminary Amendment):

An experiment was conducted on the coal formation treated according to the in situ conversion process to measure the uniform permeability of the formation after pyrolysis. After heating a portion of the coal formation, a ten minute pulse of CO₂ was injected into the formation at first production well 3806a and produced at well 3804a, as shown in FIG. 137. The CO₂ tracer test was repeated from production well 3806a to well

3804b and from production well 3806a to well 3804c. As described above, each of the three different heat sources were located equidistant from the production well. The CO₂ was injected at a rate of 4.08 m³/hr (144 standard cubic feet per hour). As illustrated in FIG. 147, the CO₂ reached each of the three different heat sources at approximately the same time. Line 3900 illustrates production of CO₂ at heat source 3804a, line 3902 illustrates production of CO₂ at heat source 3804b, and line 3904 illustrates production of CO₂ at heat source 3804c. As shown in FIG. 149, yield of CO₂ 3910 from each of the three different wells was also approximately equal over time. Such approximately equivalent transfer of a tracer pulse of CO₂ through the formation and yield of CO₂ from the formation indicated that the formation was substantially uniformly permeable. The fact that the first CO₂ arrival only occurs approximately 18 minutes after start of the CO₂ pulse indicates that no preferential paths had been created between well 3806a and wells 3804a, 3804b, and 3804c.

On page 251, the paragraph beginning on line 25:

From FIG. 151, the maximum natural water inflow is approximately 5 kg/h as indicated by arrow 3920. Arrows 3922, 3924, and 3926 represent injected water rates of about 2.7 kg/h, 5.4 kg/h, and 11 kg/h, respectively, into central well 3806a of FIG. 137. Production of synthesis gas is at heater wells 3804a, 3804b, and 3804c. FIG. 151 shows that the synthesis gas production per unit volume of water injected decreases at arrow 3922 at approximately 2.7 kg/h of injected water or 7.7 kg/h of total water inflow. The reason for the decrease is that steam is flowing too fast through the coal seam to allow the reactions to approach equilibrium conditions.

On page 254, the paragraph beginning on line 17:

Table 6 includes a composition of synthesis gas producing produced during a run of the in situ coal field experiment.

On page 256, the paragraph beginning on line 4 (as amended in the Preliminary Amendment):

FIG. 160 is a plot of calculated equilibrium wet mole fractions for a coal reaction with water. Equilibrium wet mole fractions are shown for water 4006, H₂ 4008, carbon monoxide 4010, and carbon dioxide 4012 as a function of temperature at a pressure of 2 bars absolute. At 390 °C, the produced gas includes about 89 % water, about 7 % H₂, and about 4 % carbon dioxide. At 500 °C, the produced gas includes about 66 % water, about 22 % H₂, about 11 % carbon dioxide, and about 1 % carbon monoxide. At 700 °C, the produced gas includes about 18 % water, about 47.5 % H₂, about 12 % carbon dioxide, and about 22.5 % carbon monoxide.

On page 257, the paragraph beginning on line 11 (as amended in the Preliminary Amendment):

In the embodiments ~~in~~ of FIGS. 162-164/161, the methane reactions in Equations (4) and (5) are included. The calculations set forth herein assume that char is only made of carbon and that there is an excess of carbon to steam. About 890 MW of energy 4024 is required to pyrolyze about 105,800 metric tons per day of coal. The pyrolysis products 4028 include liquids and gases with a production of 23,000 cubic meters per day. The pyrolysis process also produces about 7,160 metric tons per day of water 4030. In the synthesis gas stage about 57,800 metric tons per day of char with injection of 23,000 metric tons per day of steam 4032 and 2,000 MW of energy 4034 with a 20% conversion will produce 12,700 cubic meters equivalent oil per day of synthesis gas 4038.

On page 263, the paragraph beginning on line 2:

FIG. 177 illustrates the pressure at the wellhead of the injection wells as a function of time during the simulation. The pressure decreased from about 114 bars absolute to about 20-19 bars absolute over the first 370 days. The decrease in the

pressure was due to removal of water from the coal formation. Pressure then started to increase substantially as carbon dioxide injection started at 370 days. The pressure reached a maximum of about 98 bars absolute. The pressure then began to gradually decrease after 480 days. At about 1440 days, the pressure increased again to about 143 98 bars absolute due to the increase in the carbon dioxide injection rate. The pressure gradually increased until about 3640 days. The pressure jumped at about 3640 days because the production well was closed off.

On page 271, the paragraph beginning on line 11 (as amended in the Preliminary Amendment):

A three-dimensional (3-D) simulation model was used to simulate an in situ conversion process for a tar sand formation. A heat injection rate was calculated using a separate numerical code (CFX; AEA Technology, Oxfordshire, UK). The heat injection rate was calculated at 500 watts per foot (1640 watts per meter). The 3-D simulation was based on a dilation-recompaction model for tar sands. A target zone thickness of 50 meters was used. Input data for the simulation were based on average reservoir properties of the Grosmont formation in northern Alberta, Canada as follows:

Depth of target zone = 280 meters;
Thickness = 50 meters;
Porosity = 0.27;
Oil saturation = 0.84;
Water saturation = 0.16;
Permeability = 1000 millidarcy;
Vertical permeability versus horizontal permeability = 0.1;
Overburden = shale; and
Base rock = wet carbonate.

Six component fluids were used based on fluids found in Athabasca tar sands. The six component fluids were: heavy fluid; light fluid; gas; water; pre-char; and char. The spacing between wells was set at 9.1 meters on a triangular pattern. Eleven horizontal

heaters with a 300 m heater length were used with heat outputs set at the previously calculated value of 1640 watts per meter.

On page 272, the paragraph beginning on line 7:

FIG. 171 illustrates a plot of a ratio of heat content of produced fluids from a reservoir against heat input to heat the reservoir versus time (in days). Plot 4752 illustrates the ratio versus time for heating an entire reservoir to a pyrolysis temperature. Plot 4752-4750 illustrates the ratio versus time for allowing partial drainage in the reservoir into a selected pyrolyzation section-4750. FIG. 171 demonstrates that allowing partial drainage in the reservoir tends to increase the heat content of produced fluids versus heating the entire reservoir, for a given heat input into the reservoir.